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FIVE YEARS OF FSCBG DEVELOPMENT -- A STATEMENT OF PROGRESS

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Five Years of FSCBG Development --

A Statement of Progress

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SUMMARY

This paper summarizes accomplishments in developing the USDA Forest Service Cramer-Barry-Grim (FSCBG) model, with emphasis on the past five years and on future projections. Future development with our partners will focus on expanding the model's capability to support decision support systems for biological response, environmental effects, mitigation, real-time functions, and field operations.

It has been five years now since Continuum Dynamics, Inc. began working with the USDA Forest Service, under contract to extend development and enhance the FSCBG aerial spray dispersion model. It seems appropriate to review where we have come to date, and the exciting future this model may provide in support of the USDA Forest Service and its national and international cooperators.

FSCBG is a computer model that predicts the downwind dispersion and deposition from an aerial spray release of materials from aircraft. It includes modules for the prediction of the effects of evaporation on the spray material, the wind speed and wind direction effects from local meteorology, the penetration of spray material through forest or agricultural canopies, and the recovery of ground or canopy deposition.

FSCBG was first developed by the USDA Forest Service from U. S. Army Gaussian dispersion codes for the release of chemically active substances (Cramer et al. 1972), and adapted to the aerial spray release of pesticides over forest canopies by the H. E. Cramer Co., Inc. in Salt Lake City, UT (Dumbauld, Bjorklund and Saterlie 1980). In the early 1980s the only computational machines available were mainframes, usually with little of what we now call "user friendly" features. The first version of FSCBG was therefore platformed on the USDA Forest Service Univac 1108 machine in Fort Collins, CO. About the only people who could run the code effectively were the programmers at H. E. Cramer, Inc.

In a parallel effort the USDA Forest Service contracted Continuum Dynamics, Inc. (CDI) to continue development of the AGricultural DISPersal (AGDISP) code (Bilanin et al. 1989). This code simulates the actual Lagrangian spray paths from the spray nozzles (Reed 1954), was first written by CDI for the National Aeronautics and Space Administration (NASA), and contains models for the flow field near the aircraft itself. In the late 1980s AGDISP was ported into FSCBG to provide a "near wake" model that enhanced the overall computations in FSCBG (Bjorklund, Bowman and Dodd 1988).

In this same time period two critical breakthroughs occurred in the scientific and engineering world: (1) the development of the personal computer and the revolution in computing potential and ease that it ushered in; and (2) specifically in this field, the application of laser measuring systems to recover the atomization (drop size distribution) of spray material released from nozzles. Personal computers enabled programs far more complicated than FSCBG to be made available to nearly every interested person, while the quantification of atomization resolved a critical input need to the model.

With these advances in mind, the USDA Forest Service, through John Barry, requested that H. E. Cramer, Inc. convert the existing mainframe FSCBG code for use on the personal computer (PC). Cramer's decision was to lift the existing software -- without modification -- and attempt to make it operational on the new platform. Technical challenges delayed the transfer of an operational program to the PC, and CDI was awarded a contract to adapt and continue development of the model.

The results have been, we believe, of great benefit to the USDA Forest Service and to its national and international cooperators. In quick succession we accomplished the following:

- Within a year we were able to clear up many of the computer "bugs" that seemed to plague FSCBG operations on the personal computer, and to program in some graphical capability (Curbishley and Skyler 1989).

- With the model able to run reasonably well on personal computers, we began technology transfer training sessions with Oregon State University, opened first to USDA Forest Service personnel and cooperators, then to the private sector and foreign governments. Additional training sessions followed. To date, seven training sessions have been conducted on FSCBG.

- With persons trained in the use (and usefulness) of FSCBG, we began a user group administered by CDI under a memorandum of understanding (MOU) with the USDA Forest Service for technology transfer. The user group fields questions and suggestions, and helps users understand the model. These activities have given us many ideas for model improvements, especially in regard to graphical options, user-friendly features, and specific computations desired. To date we have 90 members in the user group.

- Then we rewrote the user interface, bringing it up to an interactive menu structure that makes it much easier to explore, to input data, to compute results, and to interpret and present them. This version, dubbed Version 4.0, went out to the user community in the first quarter of 1992 (Teske and Curbishley 1991), with updates to Version 4.3 by March 1994 (Teske and Curbishley 1994a). A helpful self-training manual was also developed (Teske, Curbishley and Skyler 1991) and a technical manual that led to a detailed discussion of the model physics (Teske et al. 1993).

- To enhance the usefulness of the model, we included a descriptive library of 109 aircraft (Hardy 1987), and a library of 276 nozzle (drop size distribution) characteristics (Skyler and Barry 1991), so that the user now can enter these libraries and select an aircraft, and a material to spray, with more ease than it would take to extract the required data from reference manuals.

- We performed a detailed sensitivity study on the influence of each input variable into FSCBG, and how its change affects deposition (Teske and Barry 1993). A more extensive sensitivity study is envisioned in conjunction with our work with New Zealand Forest Research Institute during 1995.

- We added an environmental accountancy module to FSCBG, to indicate how much spray reaches the tree crown and forest floor, drifted off target, or remained in the atmosphere. The interaction of the spray within the tree crown, the collection of drops by foliage elements, and spray deposition on the forest floor are all part of accountancy and environmental fate.

- But, most of all, we have conducted many model simulations, and compared model predictions with many past and current sets of field data, presented these results at scientific conferences, and published these results in peer-reviewed journals (Teske et al. 1991; Barry et al. 1993). Additionally, other researchers have done their own comparisons, and have found FSCBG to be all that we would like to think that it is (Anderson et al. 1992; Rafferty and Bowers 1993).

- Current work continues to look for improvements in the graphical capabilities of FSCBG, and for adding features suggested by members of the National Spray Model Advisory Committee (which meets yearly at the annual meeting of the American Society of Agricultural Engineers).

All of these features enable FSCBG to be used for any of the following:

- Planning an aerial spray project: mitigating the potential for environmental impact and supporting efficiency and efficacy by selecting the best aircraft and nozzle for a particular spray project; deciding on the best application rate, tank mix, aircraft flying height and distance between flight lines; mapping spray-on and spray-off points; developing contract specifications and an operations plan; and helping to instill public confidence in the safety of the spray project.

- Conducting an aerial spray project: updating spray parameters as weather conditions change, feeding these changes into the model and predicting the effects of these changes even as the spray project is proceeding, and thereby monitoring the performance on the spray project by the contractor.

- Post-spray evaluation of an aerial spray project: comparing model predictions with observations (thereby identifying opportunities to improve, update and enhance the model, or point out shortcomings of the spray project); assisting in the preparation of the project report and evaluating what went right and what went wrong; and critiquing the spray project and evaluating contractor performance.

- Documenting an aerial spray project, especially in case of possible use in lawsuits or as a tool for an expert witness.

- Research and development: designing field trials in a way to reduce trial and error that comes from field testing; evaluating tank mix formulations based upon their physical properties (atomization); and identifying parameters that need further research.

- Regulatory: establishing criteria for regulating the aerial use of pesticides and developing pesticide label statements.

These comments and list of uses bring FSCBG to the present. Seven areas of future usefulness of FSCBG are now being developed:

1. Continuing to develop FSCBG as a separate model, operational on PCs, maintaining its utility with advancing PC systems and on the new IBM 615 computer base the USDA Forest Service has contracted for to replace the Data General. Most of our user base is placed in the United States, in the USDA Forest Service and the private sector. These persons would want to maintain the model and be able to access it at any time, and for any sets of input data.

2. Extending the applicability of the model into real time, for use with onboard Global Positioning Systems (GPS) to track the precise location of the spray aircraft (Teske, Barry and Thistle 1994). Currently, a real-time version of FSCBG (Teske 1994) is being reviewed by the user community before releasing the source code to the manufacturers who develop these cockpit instruments.

3. Assisting the U. S. Environmental Protection Agency (EPA) and the industry-based Spray Drift Task Force (SDTF) with porting the near-wake model into their spray materials data base. At present AGDISP has been adapted for EPA's specific needs, renamed AGDRIFT, and is undergoing shakedown tests before turning it over to the EPA. When this happens, it will become the program that must be run to satisfy U. S. government spray drift restrictions, and, if it is like other models used by the EPA, it will become a permanent fixture in pesticide drift evaluation. The USDA Forest Service will have played the major role in providing the mechanism for developing this model and for its technology transfer to the EPA.

- Planning an aerial spray project: participating in a [illegible] and supporting efficiency and effectiveness [illegible] [illegible] spray project [illegible] flying height [illegible] between flight lines [illegible] points, developing contract spray [illegible] and [illegible] build public confidence in the safety of the spray project

- Conducting an aerial spray project: [illegible] spray parameters [illegible] conditions change, [illegible] these changes [illegible] of [illegible] changes [illegible] as the spray project is [illegible] the performance on the spray project [illegible]

- [illegible] spray evaluation of an aerial spray project [illegible] observations (thereby identifying [illegible]) enhance the model, or point out [illegible] the preparation of the [illegible] writing and critiquing the spray project [illegible]

- Documenting an aerial spray project [illegible] as a tool for [illegible] expert witness

Research and development: designing field [illegible] [illegible] field-testing, evaluating [illegible] physical properties (viscosities, etc.) and [illegible] needs

[illegible] for [illegible] [illegible]

[illegible] and list of uses being [illegible] are now being developed

[illegible] Forest Service [illegible] [illegible] is [illegible] the [illegible] and the [illegible]

[illegible] real time [illegible]

[illegible]

4. Assisting the Canadian Spray Drift Task Force with the further specific development of FSCBG for their regulatory needs, training them in the use of the model, and including them in the decision-making process for model improvements. There is a strong indication that FSCBG will be the model of choice in Canada for conducting all spray studies and evaluating all drift complaints. It is, again, a measure of the worth of this program that the USDA Forest Service can take credit for its development.

5. Porting FSCBG into the GypsES Decision Support System. GypsES is an expert system developed by USDA Forest Service Forest Health in Morgantown, WV, and contains extensive data bases to monitor the spread of the Gypsy moth, and the spray projects meant to contain it. At present a simplified version of FSCBG (Teske and Curbishley 1994b) is operational within GypsES as a first step towards implementing a predictive capability, and we expect to continue development of the model within this environment. While GypsES has a limited user base at present, plans are underway to expand GypsES into a more general Pest Management Decision Support System, which will greatly enhance its usefulness to the USDA Forest Service, and state and private users. FSCBG provides the decision support system with the predictions to decide what to do, with the chance to perform what-if scenarios, and with the opportunity to see what happens to a spray project almost immediately after every spray mission (by feeding the actual position of the aircraft along the flight lines -- from real-time GPS data -- into the model).

6. Porting FSCBG into the cooperative New Zealand and USDA Forest Service Aerial Application Decision Support System. At present the New Zealand Forest Research Institute (FRI) has selected FSCBG as its model of choice for predicting aerial applications and drift in that country. FRI and John Barry are now preparing a cooperative agreement (a supplement to an existing MOU) to develop a decision support system, with FSCBG as its predictive model. This effort is moving at top speed, and will reach programming stage by the spring of 1995. This decision support system will track the buffer offset distances required for certain herbicide/plant species combinations, and will seek to set productivity levels for aerial spraying. In all cases the impact on non-target species and environmental fate is of most importance.

7. Continuing to foster partnerships with researchers and natural resource managers in both the public and private sectors, for their cooperation in development and technology transfer.

Our current work involves additional model improvements in FSCBG (for the release of dry materials in addition to water-based ones, for the effects of vortices on the upwind and downwind sides of the aircraft, and with a detailed examination of the dispersion algorithms), additional field data comparisons (with recent data on the winds generated by fire-fighting helicopters and how they may in fact facilitate the spread of the fire, and with an early field trial on insect kill probability), model visualization and demonstration programs (to make it easier to visualize what FSCBG is doing). In all aspects of the modeling, we are looking to the implications of off-target drift and the environmental fate of the total released spray material. Anticipated field studies will look at the effect of time of day (how changes in atmospheric conditions during the day change deposition), while a significant model extension will involve adding the valley drift model VALDRIFT (Allwine, Bian and Whiteman 1993) as an additional available computation in FSCBG.

All in all, we can see significant usefulness for FSCBG, either in a stand-alone state, or incorporated into decision support systems.

CITED REFERENCES

Allwine, K. J., X. Bian and C. D. Whiteman. 1993. User's Guide to VALDRIFT 1.0 -- A Valley Atmospheric Dispersion Model. Pacific Northwest Laboratory: Richland, WA.

Anderson, D. E., D. R. Miller, Y. Wang, W. G. Yendol, K. Mierzejewski and M. L. McManus. 1992. Deposition of Aerially Applied Bt in an Oak Forest and its Prediction with the FSCBG Model. *Journal of Applied Meteorology* 31: 1457-1466.

Barry, J. W., P. J. Skyler, M. E. Teske, J. E. Rafferty and B. S. Grim. 1993. Predicting and Measuring Drift of *Bacillus thuringiensis* Sprays. *Environmental Toxicology and Chemistry* 12: 1977-1989.

Bilanin, A. J., M. E. Teske, J. W. Barry and R. B. Ekblad. 1989. AGDISP: The Aircraft Spray Dispersion Model, Code Development and Experimental Validation. *Transactions of the ASAE* 32: 327-334.

Bjorklund, J. R., C. R. Bowman and G. C. Dodd. 1988. User Manual for the FSCBG Aircraft Spray and Dispersion Model Version 2.0. Report No. FPM 88-5. USDA Forest Service Forest Pest Management: Davis, CA.

Cramer, H. E., J. R. Bjorklund, F. A. Record, R. K. Dumbauld, R. N. Swanson, J. E. Faulkner and A. G. Tingle. 1972. Development of Dosage Models and Concepts (two volumes). Report No. DTC-TR-72-609. U. S. Army Dugway Proving Ground: Dugway, UT.

Curbishley, T. B. and P. J. Skyler. 1989. User Manual -- Forest Service Aerial Spray Computer Model FSCBG (PC). Report No. FPM 89-1. USDA Forest Service Forest Pest Management: Davis, CA.

Dumbauld, R. K., J. R. Bjorklund and S. F. Saterlie. 1980. Computer Models for Predicting Aircraft Spray Dispersion and Deposition Above and Within Forest Canopies: User's Manual for the FSCBG Computer Program. Report No. 80-11. USDA Forest Service Forest Pest Management: Davis, CA.

Hardy, C. E. 1987. Aerial Application Equipment. Report No. 8734-2804. USDA Forest Service Equipment and Development Center: Missoula, MT.

Rafferty, J. E. and J. F. Bowers. 1993. Comparison of FSCBG Spray Model Predictions with Field Measurements. *Environmental Toxicology and Chemistry* 12: 465-480.

Reed, W. H. 1954. An Analytical Study of the Effect of Airplane Wake on the Lateral Dispersion of Aerial Sprays. NACA Report No. 1196.

Skyler, P. J. and J. W. Barry. 1991. Final Report -- Compendium of Drop Size Spectra Compiled from Wind Tunnel Tests. Report No. FPM 90-9. USDA Forest Service Forest Pest Management: Davis, CA.

Teske, M. E. 1994. FSCBG/RT: Real-Time Subroutines for Spray Cloud Prediction. Technical Note No. 94-20. Continuum Dynamics, Inc.: Princeton, NJ.

Teske, M. E. and J. W. Barry. 1993. Parametric Sensitivity in Aerial Application. *Transactions of the ASAE* 36: 27-33.

Teske, M. E., J. W. Barry and H. W. Thistle Jr. 1994. FSCBG Predictions Coupled to GPS/GIS Aircraft Tracking. Pesticide Formulations and Application Systems 15th Volume. ASTM STP 1268. H. M Collins, F. R. Hall and M. Hopkinson (eds). American Society for Testing and Materials: Philadelphia, PA.

Teske, M. E., K. P. Bentson, R. E. Sandquist, J. W. Barry and R. B. Ekblad. 1991. Comparison of FSCBG Model Predictions with Heather Seed Orchard Deposition Data. *Journal of Applied Meteorology* 30: 1366-1375.

Teske, M. E., J. F. Bowers, J. E. Rafferty and J. W. Barry. 1993. FSCBG: An Aerial Spray Dispersion Model for Predicting the Fate of Released Material Behind Aircraft. *Environmental Toxicology and Chemistry* 12: 453-464.

Teske, M. E. and T. B. Curbishley. 1991. Forest Service Aerial Spray Computer Model FSCBG Version 4.0 User Manual. Report No. FPM 91-1. USDA Forest Service Forest Pest Management: Davis, CA.

Teske, M. E. and T. B. Curbishley. 1994a. Forest Service Aerial Spray Computer Model FSCBG 4.3 User Manual Extension. Report No. FPM 94-10. USDA Forest Service Forest Pest Management: Davis, CA.

Teske, M. E. and T. B. Curbishley. 1994b. FSCBG/GypsES User Manual. Technical Note No. 94-25. Continuum Dynamics, Inc.: Princeton, NJ.

Teske, M. E., T. B. Curbishley and P. J. Skyler. 1991. FSCBG One-On-One Instruction Manual. Report No. FPM 91-8. USDA Forest Service Forest Pest Management: Davis, CA.

FSCBG BIBLIOGRAPHY

Anderson, D. E., D. R. Miller, Y. Wang, W. G. Yendol, K. Mierzejewski and M. L. McManus. 1992. Deposition of Aerially Applied Bt in an Oak Forest and its Prediction with the FSCBG Model. *Journal of Applied Meteorology* 31: 1457-1466.

Barry, J. W., R. B. Ekblad, M. E. Teske and P. J. Skyler. 1990. Predictive Models for Aerial Delivery of Pesticides. Presented at the ACAFA Symposium and Trade Show: Winnipeg, Canada.

Barry, J. W., R. B. Ekblad, M. E. Teske and P. J. Skyler. 1990. Computer Models for Aerial Delivery of Pesticides. Presented at the National Gypsy Moth Review: Ottawa, Canada.

Barry, J. W., R. B. Ekblad, M. E. Teske and P. J. Skyler. 1990. Technology Transfer -- Forest Service Aerial Spray Models. Paper No. 901017. American Society of Agricultural Engineers: St. Joseph, MI.

Barry, J. W., P. J. Skyler, M. E. Teske, H. W. Thistle and M. Quilter. 1994. *Bacillus thuringiensis* Study Summary -- Drift, Canopy Penetration and Soil Persistence. Presented at the 1994 Annual Gypsy Moth Review: Portland, OR.

Barry, J. W., P. J. Skyler, M. E. Teske, J. E. Rafferty and B. S. Grim. 1993. Predicting and Measuring Drift of *Bacillus thuringiensis* Sprays. *Environmental Toxicology and Chemistry* 12: 1977-1989.

Barry, J. W. and M. E. Teske. 1992. Predicting and Observing Fate of Sprays Released over Forests. Presented at the XIX International Congress on Entomology, Session 14S-5, The Fate of Chemicals in the Environment: Beijing, China.

Barry, J. W. and M. E. Teske. 1993. Aerial Application Computer Simulations and U. S. Experience. Presented at the Weedworks 1993 Workshop on Forestry Weed Control, New Zealand Forest Research Institute: Rotorua, New Zealand.

Barry, J. W., M. E. Teske, B. S. Grim, W. J. Roltsch and F. G. Zalom. 1993. Observing and Predicting Spray Penetration in Tree Canopies. Paper No. 931060. American Society of Agricultural Engineers: St. Joseph, MI.

Barry, J. W., M. E. Teske, J. E. Rafferty, B. S. Grim and P. J. Skyler. 1992. Predicting Spray Drift in Complex Terrain. Paper No. 921085. American Society of Agricultural Engineers: St. Joseph, MI.

Bilanin, A. J., M. E. Teske, J. W. Barry and R. B. Ekblad. 1989. Drift Predictions in Agricultural Applications: AGDISP and FSCBG. Presented at the Weed Science Society of America Annual Meeting: Dallas, TX.

Bilanin, A. J., M. E. Teske, J. W. Barry and R. B. Ekblad. 1989. Helicopter Spray Modeling and Experimental Validation. Proceedings of the ILASS-Americas 3rd Annual Conference on Liquid Atomization and Spray Systems: Irvine, CA. 93-97.

Bilanin, A. J., M. E. Teske, J. W. Barry and R. B. Ekblad. 1989. Project WIND Anemometer Tower Flyby Data Reduction. Proceedings of the AMS 19th Conference on Agricultural and Forest Meteorology: Charleston, SC. 181-191.

Bilanin, A. J., M. E. Teske, J. W. Barry and R. B. Ekblad. 1989. AGDISP: The Aircraft Spray Dispersion Model, Code Development and Experimental Validation. *Transactions of the ASAE* 32: 327-334.

Bilanin, A. J., M. E. Teske, J. W. Barry and R. B. Ekblad. 1990. USDA Forest Service Aerial Spray Dispersion Models AGDISP and FSCBG. I: Model Formulation. II: Model Validation. Pesticides in the Next Decade: The Challenges Ahead. Proceedings of the 3rd National Research Conference on Pesticides: Richmond, VA. 772-791.

Boyle, D. G. 1989. Spray Accountancy Review -- A Literature Search (two volumes). Report No. FPM 89-3. USDA Forest Service Forest Pest Management: Davis, CA.

Curbishley, T. B. 1992. 1991 CASPR Spray Aircraft Efficiency Model Validation Study. Report No. FPM 92-8. USDA Forest Service Forest Pest Management: Davis, CA.

Curbishley, T. B. and P. J. Skyler. 1989. User Manual -- Forest Service Aerial Spray Computer Model FSCBG (PC). Report No. FPM 89-1. USDA Forest Service Forest Pest Management: Davis, CA.

Curbishley, T. B., P. J. Skyler, M. E. Teske and J. W. Barry. 1992. FSCBG 4.0 Aerial Spray Model. Paper No. 921069. American Society of Agricultural Engineers: St. Joseph, MI.

Curbishley, T. B., M. E. Teske and J. W. Barry. 1991. Spray Dispersion Visualization using FSCBG 4.0. Paper No. 911051. American Society of Agricultural Engineers: St. Joseph, MI.

Curbishley, T. B., M. E. Teske and J. W. Barry. 1993. A Productivity Model for Aerial Application. Paper No. 931072. American Society of Agricultural Engineers: St. Joseph, MI.

Curbishley, T. B., M. E. Teske and J. W. Barry. 1993. Validation of the CASPR Aerial Spray Efficiency Model. *Applied Engineering in Agriculture* 9: 199-203.

Flake, H. W., M. E. Teske and J. W. Barry. 1993. FSCBG Spray Width Predictions. Paper No. AA93-003. National Agricultural Aviation Association: Reno, NV.

MacNichol, A. Z. 1994. C-47 Aircraft Spray Deposition -- Part 1: A Statistical Interpretation. Report No. FPM 94-11. USDA Forest Service Forest Pest Management: Davis, CA.

MacNichol, A. Z. 1994. User Manual for the Spread Factor Database. Report No. FPM 94-14. USDA Forest Service Forest Pest Management: Davis, CA.

MacNichol, A. Z. and M. E. Teske. 1993. FSCBG Model Comparisons with the C-130 Spray Trials. Report No. FPM 93-10. USDA Forest Service Forest Pest Management: Davis, CA.

[illegible] W. Barry and T. B. Curbishley. 1987. [illegible] the Extended Prediction [illegible]. [illegible] Charleston, WV. [illegible]

[illegible] J. W. Barry and R. E. Ekblad. 1989. [illegible] Release. The [illegible] Development and Experimental Verification. [illegible]

[illegible] K. D. Ekblad. 1990. [illegible] FSCBG Model [illegible]
[illegible] The [illegible] Pesticide Science [illegible]

[illegible] Forest Service [illegible]

Curbishley, Robert [illegible] Aircraft [illegible] Forest Service [illegible]

P. J. Skyler. 1989. User Manual [illegible] (FC). Report No. [illegible] Forest Service [illegible]

J. Skyler, M. E. Teske and J. W. Barry [illegible] FSCBG [illegible] 89-[illegible]. American Society of Agricultural Engineers [illegible]

[illegible] and J. W. Barry. 1991. Spray [illegible] 91-[illegible]. American Society of Agricultural Engineers [illegible]

[illegible] 1993. A Production Model for Aerial [illegible] of Agricultural Engineers [illegible]

[illegible] 1992. Validation of the CASPR Aerial [illegible] 102.

[illegible] Wind Predictions. [illegible] Reno, NV

[illegible]

MacNichol, A. Z. and M. E. Teske. 1993. FSCBG Model Comparisons with the 1988 Davis Spray Characterization Trials. Report No. FPM 93-12. USDA Forest Service Forest Pest Management: Davis, CA.

MacNichol, A. Z. and M. E. Teske. 1994. FSCBG Model Comparisons with the 1991 Davis Virus Spray Trials. Report No. FPM 94-2. USDA Forest Service Forest Pest Management: Davis, CA.

MacNichol, A. Z. and M. E. Teske. 1994. FSCBG Model Comparisons -- 1974 Rennic Creek Spray Trials. Report No. FPM 94-12. USDA Forest Service Forest Pest Management: Davis, CA.

Rafferty, J. E. and J. F. Bowers. 1990. Comparison of FSCBG2 and FSCBG3 Aerial Spray Model Predictions with Field Measurements. Report No. 90-2. USDA Forest Service Forest Pest Management: Davis, CA.

Rafferty, J. E. and J. F. Bowers. 1993. Comparison of FSCBG Spray Model Predictions with Field Measurements. *Environmental Toxicology and Chemistry* 12: 465-480.

Rafferty, J. E., J. F. Bowers, M. E. Teske and J. W. Barry. 1990. Comparison of Aerial Spray Model Predictions with Field Measurements. Proceedings of the ILASS-Americas 4th Annual Conference on Liquid Atomization and Spray Systems: Hartford, CT. 150-153.

Rafferty, J. E., J. M. White, J. F. Bowers and R. K. Dumbauld. 1989. Forest Spray Dispersion Study -- Comparison of Measured Deposition with FSCBG2 Model Predictions. Proceedings of the AMS 19th Conference on Agricultural and Forest Meteorology: Charleston, SC. 200-203.

Skyler, P. J. and J. W. Barry. 1990. Evaluation of C-130 Aircraft Modular Aerial Spray Systems (MASS) for High Volume (HV) Application of Herbicides -- Fuselage Booms (Trials HV-1 and HV-2). Report No. FPM 90-6. USDA Forest Service Forest Pest Management: Davis, CA.

Skyler, P. J. and J. W. Barry. 1991. Final Report -- Compendium of Drop Size Spectra Compiled from Wind Tunnel Tests. Report No. FPM 90-9. USDA Forest Service Forest Pest Management: Davis, CA.

Skyler, P. J., J. W. Barry and J. Warner. 1989. FSCBG Computer Model Predictions of Swath Widths -- 1988 Western Spruce Budworm Project -- Pacific Northwest Region. Report No. FPM 89-4. USDA Forest Service Forest Pest Management: Davis, CA.

Smith, D. B., M. H. Willcutt, D. L. Valcore, J. W. Barry and M. E. Teske. 1993. Guidelines for Aerial Atomization and Spray Drift Reduction for Mississippi Applicators. Information Bulletin No. 251. Mississippi Agricultural and Forestry Experiment Station: Mississippi State, MS.

Teske, M. E. 1989. AGDISP Comparisons with Four Field Deposition Studies. Report No. FPM 89-5. USDA Forest Service Forest Pest Management: Davis, CA.

Teske, M. E. 1989. An Examination of AGDISP Helicopter Model Comparisons with Data and Detailed Helicopter Code Predictions. Report No. MTDC 89-29. USDA Forest Service Technology and Development Center: Missoula, MT.

Teske, M. E. 1989. Parameterization of Evaporation Rates of Pesticide Droplets. Technical Note No. 89-12. Continuum Dynamics, Inc.: Princeton, NJ.

Teske, M. E. 1990. FSCBG Modeling Comparison with the Heather Seed Orchard Deposition Data. Report No. FPM 90-5. USDA Forest Service Forest Pest Management: Davis, CA.

Teske, M. E. 1990. DROPSIZE User Manual. Technical Note No. 90-10. Continuum Dynamics, Inc.: Princeton, NJ.

Teske, M. E. 1990. AGDISP User Manual Mod 6.0. Technical Note No. 90-16. Continuum Dynamics, Inc.: Princeton, NJ.

Teske, M. E. 1991. An FSCBG Primer. Report No. FPM 91-7. USDA Forest Service Forest Pest Management: Davis, CA.

Teske, M. E. 1991. SDC: Size Distribution Calculation User Manual. Report No. 9134-2810 MTDC. USDA Forest Service Technology and Development Center: Missoula, MT.

Teske, M. E. 1991. DC-3 Sensitivity Study. Technical Note No. 91-6. Continuum Dynamics, Inc.: Princeton, NJ.

Teske, M. E. 1992. ASCAS (Automatic Spot Counting and Sizing) Program Version 4.0 User Documentation. Report No. FPM 92-3. USDA Forest Service Forest Pest Management: Davis, CA.

Teske, M. E. 1992. FSCBG Technical Manual. Report No. FPM 92-4. USDA Forest Service Forest Pest Management: Davis, CA.

Teske, M. E. 1992. Correlation of the USDA Forest Service Drop Size Distribution Data Base. Report No. FPM 92-7. USDA Forest Service Forest Pest Management: Davis, CA.

Teske, M. E. 1992. Meteorological Data Reduction METDAT Version 1.0 User Manual. Report No. FPM 92-11. USDA Forest Service Forest Pest Management: Davis, CA.

Teske, M. E. 1992. Spread Factor Regression SPREAD Version 2.0 User Manual. Report No. FPM 92-12. USDA Forest Service Forest Pest Management: Davis, CA.

Teske, M. E. 1992. A Working Paper on Net Radiation Index. Report No. FPM 92-13. USDA Forest Service Forest Pest Management: Davis, CA.

Teske, M. E. 1992. FSCBG Model Input Sensitivity Study. Report No. FPM 92-14. USDA Forest Service Forest Pest Management: Davis, CA.

Teske, M. E. 1992. An Interpretation of the DC-3 Swath Width Field Trials. Technical Note No. 92-6. Continuum Dynamics, Inc.: Princeton, NJ.

Teske, M. E. 1993. The Performance of FSCBG in Downwind Drift Predictions. Report No. FPM 93-9. USDA Forest Service Forest Pest Management: Davis, CA.

Teske, M. E. 1994. *Bacillus thuringiensis* Drift Deposits on Gambel Oak Foliage -- 1992 Utah Gypsy Moth Eradication Project. Report No. FPM 94-13. USDA Forest Service Forest Pest Management: Davis, CA.

Teske, M. E. 1994. FSCBG/RT: Real-Time Subroutines for Spray Cloud Prediction. Technical Note No. 94-20. Continuum Dynamics, Inc.: Princeton, NJ.

Teske, M. E. and J. W. Barry. 1992. FSCBG Model Input Sensitivity Study. Paper No. 921086. American Society of Agricultural Engineers: St. Joseph, MI.

Teske, M. E. and J. W. Barry. 1992. Correlation of the USDA Forest Service Drop Size Distribution Data Base. Proceedings of the ILASS-Americas 5th Annual Conference on Liquid Atomization and Spray Systems: San Ramon, CA. 157-161.

Teske, M. E. and J. W. Barry. 1993. Parametric Sensitivity in Aerial Application. *Transactions of the ASAE* 36: 27-33.

Teske, M. E. and J. W. Barry. 1993. FSCBG Spray Drift Predictions. Paper No. 931101. American Society of Agricultural Engineers: St. Joseph, MI.

Teske, M. E., J. W. Barry and R. B. Ekblad. 1990. Canopy Penetration and Deposition in a Douglas-fir Seed Orchard. Paper No. 901019. American Society of Agricultural Engineers: St. Joseph, MI.

Teske, M. E., J. W. Barry and R. B. Ekblad. 1991. Preliminary Sensitivity Study of Aerial Application Inputs for FSCBG 4.0. Paper No. 911052. American Society of Agricultural Engineers: St. Joseph, MI.

Teske, M. E., J. W. Barry and J. H. Ghent. 1994. Aircraft Deposit Coverage over Canopies. Paper No. 941033. American Society of Agricultural Engineers: St. Joseph, MI.

Teske, M. E., J. W. Barry and J. E. Rafferty. 1994. An Examination of Spray Penetration Through Scrub Oak Canopies. Paper No. 941031. American Society of Agricultural Engineers: St. Joseph, MI.

Teske, M. E., J. W. Barry, P. J. Skyler, F. G. Zalom and G. W. Kirfman. 1993. FSCBG Application to Canopy Spray Penetration and Deposition. Paper No. 931062. American Society of Agricultural Engineers: St. Joseph, MI.

Teske, M. E., J. W. Barry and H. W. Thistle. 1994. Aerial Spray Drift Modeling. Environmental Modeling Volume II: Computer Methods and Software for Simulating Environmental Pollution and its Adverse Effects. P. Zannetti (ed). Computational Mechanics Publications, Southhampton, England. 11-42.

Teske. M. E., J. W. Barry and H. W. Thistle. 1994. FSCBG Predictions Coupled to GPS/GIS Aircraft Tracking. Presented at the ASTM 15th Symposium on Pesticide Formulations and Application Systems: Phoenix, AZ.

Teske, M. E., J. W. Barry and H. W. Thistle. 1994. Environmental Fate and Accountancy. Presented at the American Chemical Society Symposium on Biorational Pest Control Agents -- Formulation and Delivery: San Diego, CA.

Teske, M. E., K. P. Bentson, R. E. Sandquist, J. W. Barry and R. B. Ekblad. 1991. Comparison of FSCBG Model Predictions with Heather Seed Orchard Deposition Data. *Journal of Applied Meteorology* 30: 1366-1375.

Teske, M. E. and A. J. Bilanin. 1993. Drop Size Scaling Analysis of Non-Newtonian Fluids. Report No. FPM 93-11. USDA Forest Service Forest Pest Management: Davis, CA.

Teske, M. E. and A. J. Bilanin. 1994. Drop Size Scaling Analysis of Non-Newtonian Fluids. *Atomization and Sprays* 4: 473-483.

Teske, M. E., A. J. Bilanin and J. W. Barry. 1993. Decay of Aircraft Vortices near the Ground. *AIAA Journal* 31: 1531-1533.

Teske, M. E., A. J. Bilanin and J. W. Barry. 1993. Drop Size Scaling Analysis of Non-Newtonian Fluids. Proceedings of the ILASS-Americas 6th Annual Conference on Liquid Atomization and Spray Systems: Worchester, MA. 68-72.

Teske, M. E., A. J. Bilanin, J. W. Barry and R. B. Ekblad. 1989. AGDISP and FSCBG Aerial Spray Models -- Source Decay Coefficients. Report No. MTDC 89-28. USDA Forest Service Technology and Development Center: Missoula, MT.

Teske, M. E., J. F. Bowers, J. E. Rafferty and J. W. Barry. 1993. FSCBG: An Aerial Spray Dispersion Model for Predicting the Fate of Released Material Behind Aircraft. *Environmental Toxicology and Chemistry* 12: 453-464.

Teske, M. E. and T. B. Curbishley. 1991. Forest Service Aerial Spray Computer Model FSCBG Version 4.0 User Manual. Report No. FPM 91-1. USDA Forest Service Forest Pest Management: Davis, CA.

Teske, M. E. and T. B. Curbishley. 1992. Forest Service Aerial Spray Computer Model FSCBG Version 4.1 User Manual Extension. Technical Note No. 92-27. Continuum Dynamics, Inc.: Princeton, NJ.

Teske, M. E. and T. B. Curbishley. 1993. Forest Service Aerial Spray Computer Model FSCBG 4.2 User Manual Extension. Report No. FPM 93-17. USDA Forest Service Forest Pest Management: Davis, CA.

Teske, M. E. and T. B. Curbishley. 1994. Forest Service Aerial Spray Computer Model FSCBG 4.3 User Manual Extension. Report No. FPM 94-10. USDA Forest Service Forest Pest Management: Davis, CA.

Teske, M. E. and T. B. Curbishley. 1994. FSCBG/GypsES User Manual. Technical Note No. 94-25. Continuum Dynamics, Inc.: Princeton, NJ.

Teske, M. E., T. B. Curbishley, J. W. Barry and R. B. Ekblad. 1990. FSCBG: An Aerial Spray Dispersion Model. Proceedings of the ACAFA Symposium and Trade Show: Winnipeg, Canada. 176-180.

Teske, M. E., T. B. Curbishley, J. W. Barry and R. B. Ekblad. 1990. FSCBG -- The Forest Service Aerial Spray Dispersion Complete-Wake Model. Proceedings of the 2nd International Symposium on Advanced Technology in Natural Resources Management: Washington, D. C. 666-675.

Teske, M. E., T. B. Curbishley, J. W. Barry and R. B. Ekblad. 1990. FSCBG: An Aerial Spray Dispersion Model for Predicting the Fate of Released Material behind Aircraft. Presented at the Society of Environmental Toxicology and Chemistry (SETAC) Annual Meeting: Arlington, VA.

Teske, M. E., T. B. Curbishley and C-M. G. Lam. 1994. An Examination of the Nonwater Evaporation Algorithm in FSCBG. Technical Note No. 94-6. Continuum Dynamics, Inc.: Princeton, NJ.

Teske, M. E., T. B. Curbishley and P. J. Skyler. 1991. FSCBG One-On-One Instruction Manual. Report No. FPM 91-8. USDA Forest Service Forest Pest Management: Davis, CA.

Teske, M. E., A. Z. MacNichol and J. W. Barry. 1993. USDA Forest Service Spread Factor Technology Database. Presented at the ASTM 14th Symposium on Pesticide Formulations and Application Systems: Dallas/Fort Worth, TX.

Teske, M. E., A. Z. MacNichol and J. W. Barry. 1994. USDA Forest Service Spread Factor Technology Database. American Society for Testing and Materials Pesticide Formulations and Application Systems: 14th Volume ASTM STP 1234. F. R. Hall, P. D. Berger and H. M. Collins (eds): Philadelphia, PA.

Teske, M. E., P. J. Skyler and J. W. Barry. 1991. A Drop Size Distribution Data Base for Forest and Agricultural Spraying: Potential for Extended Application. Proceedings of the ICLASS 5th International Conference on Liquid Atomization and Spray Systems: Gaithersburg, MD. 325-332.

Teske, M. E., D. B. Twardus and R. B. Ekblad. 1990. Swath Width Evaluation. Report No. 9034-2807 MTDC. USDA Forest Service Technology and Development Center: Missoula, MT.

Teske, M. E., D. B. Twardus and R. B. Ekblad. 1990. The Evaluation of Swath Width for Gypsy Moth Suppression. Proceedings of the ILASS-Americas 4th Annual Conference on Liquid Atomization and Spray Systems: Hartford, CT. 174-178.

Thistle, H. W., J. W. Barry and M. E. Teske. 1993. Development and Validation of the FSCBG Model for the Simulation of Spray Drift. Presented at the ANPP-BCPC 2nd International Symposium on Pesticides Application Techniques: Strasbourg, Austria.

Thistle, H. W., M. E. Teske and J. W. Barry. 1993. The Relationship between In-Canopy Micrometeorology and Droplet Deposition. Paper No. 931058. American Society of Agricultural Engineers: St. Joseph, MI.